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METHOD AND DEVICE FOR PRODUCING FIBRE-REINFORCED COMPONENTS BY MEANS OF AN INJECTION METHOD

The invention relates to a method for producing fibre-reinforced plastic components made of dry fibre composite preforms by means of an injection method and subsequent low-pressure curing, as well as a device for implementing this method.

Such methods use dry fibre composite preforms in order to produce components with geometric shapes that may be unwindable, non-unwindable or not completely unwindable. The dry fibre composite preform can be a woven fabric, a multi-axis interlaid scrim or a warp-thread reinforced unidirectional preform. The above-mentioned preforms are used in the production of components made of fibre-reinforced material; they represent an intermediate process step before infiltration by resin and curing take place.

Such a method is known as a so-called resin film infusion (RFI) method wherein dry carbon fibres, carbon fibre woven fabrics or carbon fibre interlaid scrim are placed in a curing device before a specified non-liquid quantity of resin film is applied to them from the outside. The curing tools equipped and evacuated in this way are subsequently cured in an autoclave or another pressure receptacle by exposure to temperature and pressure. The use of pressure receptacles and the associated complex tools that are necessary are however very expensive, rendering such methods complex also in regard to temperatures and pressures to be maintained. The scope of application of such methods is thus limited.

Furthermore, the use of dry preform components is known from DE-OL 198 13 105 A1 which discloses a method for producing fibre composite components wherein the fibres and the matrix material are formed in a tool, forming a mould cavity, said tool comprising at least two parts, with the air situated in the mould cavity being able to escape. In this arrangement, a porous membrane is placed into the mould cavity, in front of the apertures, with the pores of said porous membranes being of such a size that air can be evacuated without hindrance while the matrix material is retained in the mould cavity.

The solution proposed in DE-OL 198 13 105 A1 does not involve any application of pressure. However, it is associated with a disadvantage in that the size of components that can be produced with this method is limited, because the matrix material can be introduced into the fibres, i.e. into the preforms, only in a limited way, provided a central matrix feed bush has been provided, because the matrix has to flow along the preform plane, i.e. along the fibres. Due to the distance to be covered and the resistance put up by the material, this direction of flow creates the largest flow resistance to the matrix. Thus, impregnation along the length of material flow is limited. As an alternative, DE-OL 198 13 105 A1 provides for the matrix to be put in place over an area. To this effect, resin reservoirs, situated on the component surface, are used, which require their own expensive resin supply device up to the preform, thus at every position posing the risk of a leakage (risk of rejects).

There is a further disadvantage in that this method can meet very exacting quality standards of the component to be produced only to a limited extent. This is because as a result of the potential resin passages through the vacuum foil

and the membrane up to the preform surface, matrix material can penetrate through the membrane in many locations of the component, thus sealing off said membrane from above. In this case, air evacuation no longer functions and pores form within the laminate, because of the reaction during the curing process (e.g. as a result of trapped air, chemical separation, volatile components etc.). Such pores, which can negatively affect the quality of the component, cannot be eliminated.

Other known low-pressure methods such as for example VARI (application unknown, DLR) do without a membrane and two-part vacuum chambers. They avoid pore formation by process management of the vacuum and temperature outside the boiling range of the matrix material. In this way no pores arise in the component. However, there is a disadvantage in that temperature and vacuum management must be very exactly adhered to at every position of the component, to avoid locally entering the boiling range of the matrix, with subsequent local pore formation. In the case of large components, such precise process management can only be realised with considerable difficulty and expense. This method has a further disadvantage in that as a result of permanent suction to maintain a vacuum, matrix material can be drawn from the component, which again can create pores. Furthermore, a resin trap or similar is necessary so as to prevent damage to the vacuum pump as a result of any matrix material issuing.

It is thus the object of the invention to create a method for producing fibre-reinforced plastic components made of dry fibre composite preform by means of an injection method, as well as a device for implementing the method, said method being suitable even for larger components, and allowing process management which is as simple as possible while at the

same time making it possible to achieve good component quality.

This object is met with the characteristics of the independent claims. Further embodiments are disclosed in the subordinate claims.

With the solution according to the invention, it is possible in particular to achieve top quality components. This is in particular advantageous in the case of highly stressed structural carbon fibre reinforced plastic components in the aircraft industry. Typical parameters indicating the quality of the components include e.g. the number of pores within the cured carbon fibre reinforced plastic laminate and the temperature resistance expressed in the glass-transition temperature of the matrix material after the process.

The solution according to the invention applies in particular to the production of composite reinforced plastic components containing carbon fibres, glass fibres, aramide fibres, boron fibres or hybrid materials whose geometric shapes may be unwindable, non-unwindable or not completely unwindable. The solution is also suitable for the production of non-stiffened or stiffened, large-area planking fields, plastics tools or tapered overlap repairs of damaged fibre composite components. Stiffening can be achieved by so-called integral stiffening (profiles made of carbon fibre reinforced plastic etc., profiles comprising a combination of sandwich and carbon fibre reinforced plastic etc.) or stiffening can be achieved by a typical sheet-like sandwich structure.

The solution according to the invention provides a cost-effective method for producing fibre reinforced components,

plastics tools and repair patches for tapered overlap repairs using vacuum injection technology and curing in a vacuum, without the use of an autoclave or without the use of overpressure.

Below, the invention is described with reference to the enclosed Figures, as follows:

Fig. 1 a diagrammatic view of a section through the device according to the invention, said device being suitable to implement the method according to the invention;

Fig. 2 a typical design of an integrally stiffened component as a sandwich hat-profile variant in the device according to Figure 1;

Fig. 3 a typical design of an integrally stiffened component as a T-profile variant in the device according to Figure 1;

Fig. 4 a typical temperature and vacuum gradient over time, for a so-called 350 °F system;

Fig. 5 a typical temperature and vacuum gradient over time, for a so-called room temperature (RT) system; and

Fig. 6 a diagrammatic view of a section through an alternative embodiment of the device according to the invention.

The device shown in Fig. 1 shows the component or dry fibre composite preform 1 to be produced, which is arranged on a

tool 3, for example by means of a mounting 5. The component or laminate can be a reinforced plastic component containing carbon fibres, glass fibres, aramide fibres, boron fibres or hybrid materials whose geometric shape may be unwindable, non-unwindable or not completely unwindable. The component or laminate is in particular suitable for the production of non-stiffened or stiffened, large-area planking fields, plastics tools or tapered overlap repairs of damaged fibre composite components. Stiffening can be achieved by so-called integral stiffening (profiles made of carbon fibre reinforced plastics etc., profiles comprising a combination of sandwich and carbon fibre reinforced plastics etc.) or stiffening can be achieved by a typical sheet-like sandwich structure. The shape of tool 2 is suitable for accommodating the component 1 or if necessary the mounting 5. Said tool 2 can be made from various suitable materials, e.g. wood, steel, sheet metal, glass or the like.

Component 1 is covered by a semi-permeable membrane 7 which is gas-permeable but which prevents penetration of matrix material. Outside the circumferential area 8, the membrane 7 is sealed as closely as possible to the component 1 by means of a seal 9 which seals the first space 10 formed by the membrane 7 and the mounting 5 or the tool surface 3. As an alternative, the membrane 7 can also surround the entire component as shown in Fig. 6. This can be achieved by means of the seal 9 (Fig. 6) or without such a seal, by designing the membrane 7 in a single piece. Between the component 1 and the membrane 7, above the entire surface 11 of the component 1 facing the membrane 7, a peel ply 13 (optional) and a spacer as a flow promoting device 15 can be arranged. The peel ply 13 and the spacer serve to hold the membrane 7 at a distance from the surface 11 of the component 1. The flow promoting

device 15 can be a type of grate or screen or a stiff woven or knitted or braided fabric which does not significantly compress when a vacuum is applied. Said fabric comprises for example metal, plastics or semi-finished textile materials.

The arrangement 17 comprising mounting 5, component 1, membrane 7 with seal 9 as well as peel ply 13 and flow promoting device 15, is covered by a foil 19 which is impermeable to gas. Around the circumference of the membrane 7, said foil 19 is sealed on the tool 3 by means of a seal 21 so that the second space or interior space 27 which is formed by the surface 23 of the tool 3 and the internal wall 25 of the foil 19, is sealed off from the surroundings. A ventilation fabric 32, for example a woven glass fabric or a fibrous web or similar, is placed between the foil 19 and the membrane 7. This ventilation fabric 32 leads the air and gasses, which were removed by suction through the membrane, from the interior space 25, along the membrane surface, for removal by suction through the vacuum pump 29. This interior space 27 can be evacuated by means of a vacuum pump 29 (not shown) and a respective gas pipe 31 which leads into the interior space 27. In addition, a second pipe 33 leads into the interior space 27, through which pipe 33 matrix material and in particular resin, can be introduced into the interior space 27.

To feed matrix material into the component 1, hoses or pipes 33 which are connected to a resin reservoir (not shown) lead into a space 25 situated in the first space 10. The tool and the reservoir for the matrix material are located on hot plates, within a heated chamber, within a heatable liquid (oil bath or similar) or within a controllable oven, if the

selected resin system requires thermal treatment during injection.

The foil 19, the peel ply 13, the membrane 7, the ventilation fabric 32 and the flow promoting device 15 all must be resistant, for the duration of the process, to the matrix systems used. In addition they must also be resistant to the temperatures which occur during the process. Depending on the particular geometric shape to be produced, placement onto such a shape by stretching, fold formation or similar must be possible.

The foil 19 is a gas-impermeable state-of-the-art vacuum membrane with the characteristics mentioned above. Its task is to seal off the second space 27 from the surroundings. Typical materials for this are foils or rubber membranes. Examples for a 180 °C (350 °F) application include for example foils based on PTFE, FEP etc. Other materials may be considered, depending on the selected matrix system and its specific curing temperature, taking into account the above-mentioned requirements.

The peel ply 13 serves to facilitate separation (by peeling), after completion of the process, of the flow promoting device 15 filled with matrix material from the component 1, because all the process materials mentioned are only used as auxiliaries in the production of the component 1. The peel ply 13 is designed to resist permanent connection with the matrix material and the surface of the component. This is achieved by a particular surface structure of the peel ply and/or by additional non-stick coatings (such as for example PTFE, silicon or similar). Typical materials are for example woven glass fabrics, woven nylon fabrics or similar. The peel

ply must be gas-permeable and also permeable to matrix material in both direction.

The membrane 7 is a semi-permeable membrane e.g. made of a technical plastic material which meets the process conditions as far as temperature resistance and media resistance are concerned. Furthermore, this membrane is gas-permeable but impermeable to liquids with viscosities that are comparable to water. This behaviour is achieved by gas-permeable pores situated in the membrane, said pores being distributed on the surface of the membrane over a greater or a lesser area. The size of the pores is selected such that the matrix system cannot penetrate them. The thickness of the membrane is in the range of tenths of a millimetre. Adequate flexibility for draping and forming is provided by the use of typical plastic materials.

The ventilation fabric 32 above the flow promoting device 15 serves to convey the air and other volatile components sucked through the membrane, for removal by suction to the vacuum pump 29. This material can comprise any material as long as it provides adequate temperature resistance and media resistance to the materials necessary during the process, and as long as the conveyance of air in longitudinal direction is possible. Fluffy mats, woven fabrics, knitted fabrics, braided fabrics and similar are used for this purpose, whereby said articles can be made from metal, plastic or other materials.

The flow promoting device 15 enables distribution on the surface of the component 1, of the matrix material which reached space 25 via the matrix supply pipe. The flow promoting device 15 thus assumes the function of a flow

channel. The flow promoting device 15 must maintain a minimum thickness when subjected to the vacuum build-up of foil 19, so as to enable such material flow. It is thus a spacer which forms a flow channel between the membrane 7 and the component 1. The flow promoting device can be a braided fabric, a woven fabric, a knitted fabric or similar, with, if at all possible, a wide-meshed structure so as to create little flow resistance. Any materials can be used, e.g. metal or plastic or similar, as long as the above-mentioned common minimum requirements (temperature and media resistance) are met. To support the transport of the matrix, the matrix supply pipe 33 can reach as far as required into the first space 10. One branch or several supply pipes are permissible. Within the first space 10, this matrix supply pipe may comprise apertures, for example holes, transverse slots, longitudinal slots or similar. These assist resin transport in the flow promoting device.

Figs. 2 and 3 show the device according to the invention as shown in Fig. 1, except that each figure shows a different component 1. The reference numbers for components of the same function are the same in these figures. It is evident that the device according to the invention is suitable for components of almost any shape. Fig. 2 diagrammatically shows a planking field (component 1) which in one direction is stiffened by means of hat profiles. These hat profiles comprise a foam core 35 or a core formed from any material, with a closed surface and with dry fibre composite preforms 34 placed thereon, said dry fibre composite preforms being hat-shaped. The fibre composite preforms 34 are made from materials which are identical or similar to those of component 1. The foam core 35 and the preforms 34 form part of component 1.

The component 1 of Fig. 3 is also a planking field which in longitudinal direction is stiffened by one or several T-profiles 36. Component 1 which is to be produced according to Figure 3 thus comprises the individual components 1 and 34. The T-profiles 34 are made from materials which are identical or similar to those of component 1. In addition, this component variant requires a support 37 for fixing the dry T-profiles 36 which in their non-impregnated state are unstable. These supports 37 can be made from typically rigid or semi-flexible tool materials such as e.g. metal, wood, rubber, plastic etc. Since there is direct contact with the matrix material, this material of the supports 37 must keep its form in relation to the matrix material during the process.

Figs. 4 and 5 show typical gradients of various resin system classes as a vacuum gradient 91 and a temperature gradient 92, with the gradient shown in Fig. 4 relating to a 350 °F system and the gradient shown in Fig. 5 relating to an RT-system.

The temperature and vacuum gradients can be broken down into at least two phases, the injection phase 101 and the curing phase 103. A tempering phase 102 may be provided after these phases. In the injection phase 101 the temperature is lower than in the curing phase 103.

The temperature gradient and the vacuum control are such that the cured component is of optimum quality with few to no pores and a suitable fibre volume fraction being achieved. The specifications for temperature are determined by the materials requirements of the matrix material. Irrespective of the matrix material selected, during the entire process right through to curing, i.e. the condition in which the matrix material has changed its aggregate state from liquid to

irreversibly solid, the vacuum can be kept at a constant level. Normal values and tolerances which must be observed include for example 1 to 10 mbar (absolute pressure, near the ideal vacuum). After curing 103, it is no longer necessary to maintain a vacuum. The necessary temperature gradients are characterised as follows: during the injection phase 101 at full vacuum, a temperature is required which is determined by the viscosity curve of the matrix material. The temperature is selected such that the matrix material becomes liquid enough to reach the interior space 25 via the supply pipe 33 by means of vacuum suction. This is the minimum temperature necessary for the process. At the same time this temperature must not be so high as to cause curing (loss of viscosity, solid state of the matrix). Therefore (depending on the matrix material selected), the process temperature is set such that injection is possible (slight viscosity) and that the remaining time to curing for the injection, i.e. near-complete filling of the interior space 25 with matrix material is adequate (technical term e.g. gel time). Typically, the necessary viscosities during the injection phase range e.g. from 1 to 1000 mPas. Typical temperatures for a 350 °F (180 °C) system are e.g. 70 to 120 °C for the injection phase 101, approx. 100 to 180 °C for the curing phase 103, and values of approx. 160 to 210 °C for the tempering phase 102.

For selected matrix materials, e.g. RT matrix materials, the following variant is advantageous: injection temperature 101 equals curing temperature 103 equals tempering temperature 102.

The vacuum is established before the injection phase 101 (Fig. 4) or before it. In the method according to the invention a vacuum which typically ranges from 1 to 10 mbar, is generated

for injection, said vacuum extending to completion of the curing phase. Said vacuum should not be reduced.

The method according to the invention is described below:

Dry materials (e.g. carbon fibre reinforced interlaid scrim, woven fabric, etc.) are positioned as specified in the design, and thus a laminate structure is formed from the individual layers of preform. The tool has been pre-treated to separate, i.e. by means of release agents or separating foil and peel ply (altogether this constitutes the design 5 on the underside of component 1). This prevents sticking of the matrix material to the tool and allows removal of the component (stripping) from the tool surface. The dry material of the component 1 preferably comprises the peel ply 13. In addition, a so-called flow promoting device 15 is simply placed above this construction. In the case of complex components, local lateral attachment, e.g. with temperature-resistant adhesive tape, is advantageous. The membrane 7, which is air-permeable but not liquid-permeable, is placed onto this flow promoting device 15 and sealed off by means of the seal 21. Then the ventilation fabric 32 is placed on the membrane 7 and sealed off from the surroundings by means of the foil 19 and the seal 21. During this procedure, the matrix supply pipe 33 and the vacuum pipe 29 are put in place with commercially available bushings and seals as shown in Fig. 1.

After placement of the above-mentioned materials and the foil or vacuum film 19, the first space 10 is evacuated using the vacuum pump. At the same time a reservoir containing matrix material is connected to the system, to introduce matrix material into the first space 10. The vacuum results in a

drop in pressure so that the matrix material is sucked from the reservoir into the evacuated first space 25. After this, the matrix material flows through the flow promoting device 15 and the supply pipe 33 and is distributed on the surface of the component, more or less unhindered, and almost irrespective of its viscosity characteristics. Any air present is disposed of through the membrane 7, as a result of permanent evacuation, by suction, of the interior space 27. There is no flow of matrix material within the laminate construction which is characterised by considerable flow resistance. Instead, the infiltration of matrix material takes place from the component surface vertically downward into the laminate. The maximum flow path at each position of the component is thus directly related to the component thickness at this point. The flow resistance is thus minimal. Consequently it is now possible to use resin systems which due to their viscosity were hitherto unsuitable for infiltration, and it is possible to create components of large dimensions.

Membrane 7 serves the purpose of preventing the occurrence of local air cushions. If for example the flow fronts which form, close up, creating a closed air cushion in component 1 of the interior space 25 without binding to the vacuum outflow of the air, no resin can flow into this air cushion. A defect (no impregnation) would be the result. The air-permeable membrane 7 prevents this effect because at every position in the component, air can always move vertically to the surface, through the membrane, into a resin free space which can be ventilated, of the vacuum build-up 27. From there, above the membrane 7, the air is removed by suction, via the vacuum connection 29 by means of the ventilation fabric 32. The membrane is resin-impermeable. There is thus no need for monitoring the flow fronts because the process of impregnation

is self-regulating. The degree of impregnation is directly related to the quantity of resin supplied and thus available to the process, as well as being directly related to the quantity of fibre supplied.

As soon as complete impregnation has taken place, curing is carried out at a suitable temperature while the vacuum is maintained at the same level. In known processes, the bubbles arising as a result of the chemical process (matrix boiling, volatile components etc.) would lead to pore formation in the finished component. This is now prevented by the membrane 7, because permanent ventilation vertical to the surface of the component takes place through the membrane.

On completion of curing, the component can be stripped. This means that all process materials are removed from component 1, e.g. by peeling them off manually, and the component can be separated from the tool 3. Depending on requirements, the now stripped hard component with preforms impregnated with matrix, can be subjected to a pure thermal after-treatment (tempering in step 102). Tempering can also take place prior to stripping, but this is not necessary. Tempering after stripping will reduce the time during which the tool is tied up.

The maximum size of components which can be produced with the method according to the invention is almost unlimited. A natural upper limit is more likely to be dictated by considerations associated with handling of the component (transport etc.) rather than with the method itself. There is no minimum size for these components. The maximum achievable thickness depends on the resin types used and the available injection time. This injection time is determined by economic

rather than technical limits. Other undesirable side effects such as for example an exothermal reaction during curing, depend only on the resin system rather than on the method.

In summary, the invention relates to a method for producing fibre-reinforced plastic components made of dry fibre composite preforms by means of an injection method for injecting matrix material. In this method, removal by suction, of air from the second space 27 takes place, resulting in a pressure drop from the first space 10 to the second space 27, with matrix material being sucked from the reservoir into the evacuated first space 10. Because of the flow promoting device 15, said matrix material enters the preform 1 vertically, in a distributed manner, above the surface 11 of the preform 1 facing the membrane 7. By combining the functions of distributing the matrix material above the component surface through the flow promoting device, and the possibility of area-like ventilation above the component, as well as the flow promoting device, through the membrane foil, the desired quality is achieved with curing in a vacuum, without the use of overpressure.